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SALT FREE ACIDULANT STORAGE OF PICKLING CUCUMBERS FOR FURTHER PROCESSING

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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The Ohio State University

1975

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INTRODUCTION

In this country over 1.3 million acres of cucumbers for pickling are harvested annually representing a total value for the commodity of $60.3 million and a total retail value of processed pickles approaching $500 million. Since 1965 the total value of the crop for the country has doubled and has in Ohio increased five-fold. In terms of acreage, cucumber pickles represent Ohio's second most important crop for processing. More importantly, this commodity represents the sharpest increase in volume and interest on the part of the processors of any of Ohio's present seasonal crops. Ohio is second only to California in yield per acre and is among the leading states in total production and value per ton.

Part of this dramatic growth has been due to the introduction of the pasteurized fresh-pack pickle products. These pickle products are prepared from uncured unfermented cucumbers and are packed in a vinegar solution with various other spices to give the characteristic flavor of the particular type of pickle. The relatively high consumer preference for the fresh-pack product has been purported to be due to the inherent crispness of this processed commodity.
Presently about 40 percent of the cucumber crop for processing is fresh-packed.

Since not all of the cucumber crop harvested in the season can be handled as fresh-pack products, the processor has required a means of holding cucumbers for year-round processing. This need is amplified when one considers the convenience of year-round processing in being able to fill orders when received accommodating an efficient warehouse turnover and distribution. The pickle processor has traditionally employed brine preservation or "vat curing" to store cucumbers.

Pickle products of the cured type are described as being cured by natural fermentation in a salt brine solution (NaCl) which may contain dill herb or other flavorings (2). The function of the salt in the process is to enable the desirable salt tolerant lactic acid microorganisms to metabolize plant sugars and thus produce the acid necessary to cure the cucumbers and to inhibit the growth of undesirable spoilage microorganisms. Further, nutrients from the cucumber diffuse into the brine allowing the lactic acid microorganisms to grow.

Along with the salt, the pack-out ratio is extremely important in determining the success of the fermentation. The pack-out refers to the weight in solids (cucumbers) to the weight in liquid (brine) calculated as water at 8.34 pounds per gallon (43). The amount of cucumber solids in
the brine will influence the buffering capacity of the brine. This is important because any increase in the buffering capacity will aid in stabilizing the pH drop and thereby allow the lactic acid producers to ferment more of the sugar and thus aid in the preservation of the cucumber pickles.

Owing to the nature of the salt brining process the industry has been faced with certain recurring problems. It has been conservatively estimated that the pickle industry loses well over a million dollars annually due to soft and bloating or hollow pickles naturally formed during the salt brining process. These losses are incurred because defective pickles can only be used in the production of low profit items such as relish rather than whole pickles.

Another major problem facing the industry is the recurring cost and subsequent disposal of the salt used in brines. It has been estimated that each year the processing industry uses 200 million pounds of salt to brine products such as olives, pickles, cauliflower, beets, and cabbage (28). Further, it was estimated that at approximately 13 dollars per ton there would be a recurring expenditure of over $1.25 million a year just for salt.

Because of the nature of the brining operation most of the salt used during the year is discharged in the local streams, ponds, and sanitary sewer systems. The disposal of the brine is extremely difficult due to the corrosive
nature of the salt and also the fact that the waste is composed of a mixture of non-biodegradable salt and organic solids. The chlorides from spent brines can lead to an increase in the chloride ion content of local streams and decrease the water quality. The potential pollution problem can be appreciated when one considers that annually processors must handle well over 30 million gallons of brine ranging in salt content from 12 to 15 percent. Recently the concern for the environment has stimulated researchers to look for alternative methods for the disposal of spent brines without causing water pollution. Generally the research has been directed to recycling the salt or reducing the salt content of the brine.

Another advantage to an alternative method for brining cucumbers is the special dietary needs of a significant segment of our population. Cucumber pickles and relishes are currently on the list of foods not allowed on sodium restricted diets since they contain 1.5 to 3.5 percent sodium chloride.

Recently the American Medical Association has become increasingly concerned about the sodium level in diets for certain patients. Low sodium diets have been prescribed for hypertension, congestive heart failure, and diseases associated with the retention of extracellular fluids. Nevertheless, patients restricted to these diets have often complained about and rejected large portions of their diet
because they say the food is bland and tasteless.

A study was undertaken by Bell et al. (16), after consultation with hospital dietitians who expressed a need for low sodium pickles, to evaluate low sodium pickle products to enhance the palatability of low sodium diets. According to the authors, since raw cucumbers are relatively low in sodium containing 0.9 to 6.0 mg per 100 g fruit, low salt processing with salt substitutes would produce pickles which are within the tolerance range for sodium restricted diets.

The purpose of this study was to determine the feasibility of storing cucumbers in salt free acidulant solutions and mixtures of acidulant solutions as a possible alternative to brine preservation. The objectives of this study were to:

1. objectively and subjectively determine the effects of acidulant storage on cucumber firmness (texture),

2. subjectively determine the effects of acidulant storage on bloater formation,

3. objectively and subjectively determine the effects of acidulant storage on cucumber appearance or color,

4. subjectively determine the organoleptic acceptability of finished cucumber pickles which were stored in acidulant solutions.
A review of the literature provided information concerning the factors affecting the quality of cucumber pickles as well as the conditions producing defects and spoilage commonly associated with the uncontrolled natural fermentation of brined cucumbers.

Formation of Color

Traditionally, color evaluation of cucumber pickles has been primarily a subjective determination of skin and internal color. Normally, emphasis has been placed on the uniformity of color with an absence of bleached areas.

Color as a quality attribute determining grades of pickles represents 20 points of the total scoring factors (2). According to these guidelines, for cured cucumbers, skin color ranges in the case of Grade A from a translucent light green to dark green with no more than 10 percent varying markedly from the typical color. In the case of Grade B, the color range is light to dark green with no more than 25 percent varying markedly from the typical color. Fresh-pack pickle products for Grade A range from opaque yellow-green to green with not more than 15 percent varying. Grade B fresh-pack pickles range from yellow-green
to green with no more than 30 percent varying from the typical color.

During the brine fermentation process, the color conversion of the raw cucumber is due to both physical and chemical changes. Physically, the change in appearance of a cross-section of the cucumber from a snow-white to a waxy transparent color is due primarily to a large amount of occluded air in the fresh cucumber tissue which is later expelled (83). Chemically speaking, the acid produced during fermentation converts chlorophylls to pheophytins (68, 70).

A molecule of chlorophyll consists of four 5-membered pyrrole groups arranged to form a porphyrin ring as shown in Figure 1 (70). In chlorophyll, a magnesium atom is held by the nitrogen on two of the rings by ordinary covalent bonds. The other two nitrogens share two electrons with the magnesium to form a coordinate covalent bond (indicated by the dotted lines). The color of the unsaturated chlorophyll is dependent on the resonance of the conjugated double bonds (68). Because of the ring structure these double bonds migrate around the ring (68).

Changes in the chlorophyll molecule which may affect the color include loss of magnesium, removal of the phytol and methyl ester groups, and oxidation of the ring (70). The chlorophylls are extremely sensitive to degradation by acids and particularly carboxylic acids such as acetic and
lactic. In the presence of acid, the magnesium of the chlorophyll molecule is displaced and replaced by two hydrogen atoms (68, 70). The magnesium free molecules are known as pheophytins a or b (from chlorophylls a or b). Pheophytin a is a grayish green color and usually predominates over pheophytin b which is a dull yellowish-green color (70). The reaction may be written as shown in Figure 2.

Another change in the color of the raw cucumber is due to the esterase enzyme, chlorophyllase, which specifically catalyzes the hydrolysis of the phytol ester linkage of the chlorophyll yielding chlorophyllides (70). Part of the dull olive-green color of the cured pickle stock results from this enzymatic conversion to chlorophyllides. The chlorophyllides subsequently lose magnesium in the presence of lactic acid yielding pheophorbides. The pheophorbides usually predominate over pheophytins in cured cucumber pickles (70).

There has been little research conducted concerning the factors affecting cured pickle color. Jones et al. (62) recognized the need for a fundamental study of the nature of the pigments in fresh cucumbers and the influence of harvesting, brining, finishing, and storage practices on the color of finished pickles. In this study cucumbers were brined according to a simulated commercial procedure and analyzed at frequent intervals during 207 days for
Figure 1. The Structure of the Chlorophyll Molecule.

Figure 2. The Conversion of Chlorophyll to Pheophytin

\[
\text{Chlorophyll} \quad \overset{- \text{Mg}}{\longrightarrow} \quad \text{Pheophytin}
\]

\[
\text{Chlorophyllide} \quad \overset{\text{Phytyl}}{\longrightarrow} \quad \text{Pheophorbide}
\]
changes in the pigments. The extent of the chlorophyll conversion to pheophorbide and pheophytin was determined and the results indicated that the final ratio of pheophorbide to pheophytin was approximately 4:1 (62). Further, this study revealed that the carotenoids consisting primarily of beta-carotene and xanthophylls were also found to undergo some destruction during fermentation.

**Factors Affecting Texture**

Texture is an extremely important quality attribute of food commodities. The word "texture" is derived from a Latin root meaning "to weave" and was first applied to certain tactile and visual characteristics of fabrics. The term texture evolved to have a more general meaning and was applied to other classes of objects including food. According to the Taste Testing and Consumer Preference Committee of the Institute of Food Technologists, texture, as a term used by persons engaged in sensory evaluations of foods and beverages is the totality of those properties of a food stuff apprehended by the eyes, skin, and muscle senses in the mouth including roughness, smoothness, and graininess (65). Other workers in the food industry have adopted a more restricted view of texture as being the mingled experience derived from the sensations of the skin in the mouth after ingestion of a food or beverage.
These sensations include density, viscosity, surface tension, and other physical properties.

Texture represents 30 points of the total 100 scoring points in determining grades of cucumber pickles. Traditionally, within the industry, the firmness or texture of salt stock pickles has been determined by hand feel. Emphasis has been placed on the freedom from "flabbiness" and soft areas. Bell et al. (8) indicated that the USDA Fruit Pressure Tester, (64), was a reliable instrument for measuring salt stock firmness. According to these authors the Fruit Pressure Tester is much more sensitive than the hand for detecting losses in firmness from 20 to 30 percent. Various other researchers have adopted and utilized this instrument to measure cucumber firmness (6, 12, 15, 20, 50, 55, 56, 57, 60, 69, 78). More recently, the Instron Universal Testing Machine has been employed to determine cucumber firmness and carpel strength (19, 56, 57, 80).

The influence of cultivar on cucumber firmness has been demonstrated in previous studies. Breene et al. (19) found rather wide differences in the textural quality of raw fruit of 24 genetically diverse cucumber cultivars. This study measured the parameters of brittleness, hardness, elasticity, cohesiveness, gumminess, and chewiness revealing a positive correlation between green and salt stock for each of these parameters. Fellers and Pflug (50) revealed the influence of cultivar on firmness by comparing Fruit
Pressure Test readings on raw and fresh-pack number 2 size fruit. Jones et al. (61) investigated the suitability of 19 cultivars and strains of cucumbers for salt stock production. Results of this study showed consistent differences in firmness among cultivars of a magnitude believed to be commercially important. These differences were obtained with cultivars brined in the same container and shown to be free of enzymatic softening.

Jones et al. (61) also reported that as the size of the cucumbers that are brined increases, the firmness of the resulting brine-stock pickles also increases. According to the authors, this amounts to 1 to 1-1/2 pounds between sizes, depending upon how closely the grading is within a given size. Breene et al. (20) stated that the rupture force for a thin skinned cultivar increased with increasing size but did not increase with a standard firm cultivar. Su and Humphries (80) found that the puncture force increased with the increasing cucumber size for 0.018 and 0.030 inch diameter plungers, but not for the 0.083 inch plunger.

Bell et al. (6) pointed out that the softening of cucumbers brined under commercial conditions has been shown to be enzymatic in nature and primarily the result of the hydrolytic activity by a system similar to polygalacturonase. The authors arrived at this conclusion after adding polygalacturonase to one-year old cured cucumber salt stock
material which was very firm, 18 pounds as indicated with the USDA Fruit Pressure Tester. The salt stock firmness was reduced by 50 percent in 42 days and 66 percent after 62 days compared to a control. Also test results indicated that the optimal pH for polygalacturonase is 4.0 and that the enzyme is functional up to 21.3 percent salt. This enzyme system catalyzes the glycosidic hydrolysis of pectin or pectic acid composing the middle lamella of the cucumber tissue. Etchells et al. (35) reported that cellulolytic enzyme systems were also found to be present in curing brines and may contribute to the total softening action.

Bell et al. (6) discovered still another enzyme which may be involved in cucumber softening. This enzyme, pectinesterase, catalyzes the de-esterification of pectin by removal of methoxyl groups. Bell et al. (7) determined the presence of cucumber pectinesterase in 6 vats of cucumbers undergoing active fermentation. The activity in both extracted cucumber juice and in brine was low indicating to the authors that this enzyme may be inactivated by lactic acid. Further, seeds, leaves, petioles, stems, flowers, and fruit of the pickling cucumber were found to contain the esterase enzyme.

Dahodwala et al. (26) studied the activities of fungal pectinesterase and fungal pectinase at various pH and NaCl levels. Test data revealed that both enzymes are effective in the pH range of 3.5 to 5.0. Fungal
pectinesterase was found to be nearly independent of salt concentration. Nevertheless, data presented by Bell et al. (7) showed that the NaCl concentration for optimal enzyme activity was 0.15 to 0.20 M which is similar to that of tomato esterase.

Bell et al. (12) demonstrated that as purified pectinolytic enzymes were incorporated into cucumber brines of increasing salt concentration, firmness increased as the brine strength increased. According to the authors even though firmness increased with increasing brine strength, cucumbers still lost 30 percent of their initial firmness in 4 weeks with 1 ppm polygalacturonase. The authors acknowledged that the results of their study indicated that a decrease in pectinolytic softening would be expected where higher initial brine strengths were employed. However, substantially increasing the brine strength to increase firmness could run the risk of increasing bloater damage resulting from a more gaseous fermentation.

Etchells et al. (36) explained that the sources of these enzymes are known to be filamentous fungi naturally present during brine fermentation. Further, according to these authors, the softening enzyme systems are introduced into the curing brines by way of fungus-laden flowers that remain attached to the fruit, and to a lesser extent by the fruit itself. Similarly, Bell et al. (10) reported considerable enzyme activity, pectinolytic and cellulolytic, from
cucumber flowers in northern brining areas. Along with the filamentous fungi from the cucumber flowers and tissue, Bell and Etchells (9) indicated that numerous salt tolerant yeasts commonly associated with brine fermentation possessed pectinesterase activity.

Post-harvest handling can also affect the potential for softening of salt stock. Etchells et al. (47) revealed that storage temperature and relative humidity have a considerable effect on the increase of microbial cucumber skin counts during storage prior to filling the brine tanks. The growth of mold species was encouraged by high moisture and temperature conditions. According to the authors, increased levels of pectinolytic and cellulolytic enzymes correlated closely with the development of mold growth.

Fabian and Fulde (49) discussed factors during early fermentation which could lead to spoilage. As the authors explained, the first 3 or 4 days are critical to the success of the fermentation. During this period, various groups of microorganisms are becoming adjusted to their new environment. At this time, unfavorable factors such as bacteriophages and antibiotics develop; and unfavorable conditions such as Eh, oxidation-reduction potential, and pH are becoming adjusted in the brine. Further, the faster the rate of salt penetration into the fruit and subsequent equilibration the quicker favorable conditions are established for the desirable lactic acid microorganisms. The
earlier the equilibration and establishment of lactic acid microorganisms, the more successful the fermentation since undesirable microorganisms would be inhibited. According to these authors, since the rate of salt penetration is much faster in small size fruit, less spoilage is obtained with smaller sizes than with larger fruit.

Direct incorporation of enzyme inhibitors proved to be beneficial in blocking cucumber softening. Etchells et al. (37) demonstrated that the pectinolytic and cellulolytic enzymes of cucumber flowers, when added to small scale cucumber fermentations, were effectively reduced in activity by a crude extract of Scuppernong grape leaves (Vitis rotundifolia). The reduction in activity was directly related to the enzyme inhibitor concentration. Porter et al. (76) investigated the probable identity of the pectinase inhibitor in grape leaves. His studies revealed the water soluble inhibitor was a "tannin" or "tannin-like" material removable from leaf extracts.

Bell et al. (13) screened various plant leaf extracts for their ability to inhibit pectinase and cellulase enzymes. Test results showed that 29 different plants had varying degrees of success inhibiting one or both of these enzyme systems. Bell et al. (14) indicated that a brine extract of sericea (Lespedeza cuneata Don) and a freeze-dried substance isolated from this plant displayed the ability to substantially reduce pectinolytic and
cellulolytic activity. The authors also pointed out that the addition of sericea, either as a brine extract or the isolated substance, appeared to exert no lasting inhibitory effect on lactic acid groups.

Bell et al. (8) devised a rapid test for enzymatic activity through measurements of viscosity. Research has shown that the maximum concentration of softening enzymes diffused out of the flowers and into the brine within 24 to 48 hours after the vats were filled (36, 77). With this information, southern briners have been able to control softening spoilage by simply draining off the original enzyme-laden cover brine 36 to 48 hours after filling the tank and replacing with a new brine.

Bell et al. (15) compared the influence of acetic acid with lactic, citric, malic, and oxalic on firmness in pasteurized fresh-pack cucumber storage tests. In this study, texture was determined with a Magness Taylor Pressure Tester. For evaluation purposes a rating scale of 18 pounds and above was considered very firm, 14-17 pounds firm, and below 14 pounds inferior. Results indicated that when cucumbers were packed in quart jars without heating and with water, acetic acid, or lactic acid the corresponding pressure tests were 19.3 very firm, 15.8 firm, and 17.9 firm. However, when jars were heated for 0 to 240 minutes at an internal product temperature of 165° F, firmness readings were progressively reduced.
In another part of this study (15), acids were added separately to cover brines to give an equilibrated pH of 4.0. The jar samples, after 4 months, yielded firmness values of 15.8 pounds for acetic at 2.05 percent equilibrated acid, 15.3 pounds for lactic at 0.47 percent, 15.7 for citric at 0.45 percent acid, and 15.7 pounds for malic equilibrated at 0.45 percent. According to the authors oxalic acid reduced the cucumbers to mush within 4 months. After 8 months storage, cucumbers packed in acetic acid retained the highest degree of firmness. The authors attempted to explain the loss of texture observed during the study as being due to the shift in calcium from the pectic substances between the plant cells.

Traditionally, pickle packers have attempted to increase the firmness of cucumber pickles during processing by the addition of alum salts. Etchells et al. (45) demonstrated that aluminum sulfate, the most commonly used alum salt, caused a noticeable reduction in firmness of stored pickles.

Factors Affecting Bloater Formation

The term "bloaters" has been defined by Jones et al. (59) as either salt stock or dills which float on the brine when the head of the container is removed or to cucumbers which are hollow or have large spaces in the interior. The most common type of bloater is the "balloon" type which has
the seed mass more or less removed to a thin layer which lies against the inner surface of the rind. According to these authors, this type of bloater when cut lengthwise has the appearance of a trough and when cut crosswise has the appearance of a ring with a large central cavity. In the "lens" type of bloater, the gas pockets are smaller than balloon types and are lenticular or biconvex. These separations generally occur perpendicular to the longitudinal axis of the fruit. The "honeycomb" classification of bloater type is categorized by small gas pockets generally around individual seeds giving a honeycomb appearance. Examples of slight, moderate, and advanced degrees of "honeycomb" and "lens" bloaters are shown in Figure 3.

Economic losses due to bloater defective pickles have continually perplexed the brining industry. It has been estimated that the pickle industry loses well over a million dollars annually due to bloater damage (34). These losses are incurred due to the fact that the hollow pickles must be used for less valuable items such as cut pickle or relish.

Previous research has shown that many factors can affect bloater damage. Pederson and Albury (73) studied the absorption of salt by cucumbers during fermentation. Their work revealed that bloating tendency increased when either the stem or blossom end of the fruit was sealed which indicated to the authors the importance of the
Figure 3. Illustration of Slight, Moderate, and Advanced Degrees of "Honeycomb" and "Lens" Bloaters
vascular system. According to the authors, drying of cucumbers and subsequent closing of the vascular system interferes with the natural transfer of salt brine into the fruit and nutrients out of the fruit thereby increasing bloating. Further, the authors stated that among cucumbers of advanced maturity the locules of some fresh cucumbers will show separation. This amount of separation will increase with drying which may help explain the greater tendency toward bloating with large size cucumbers. The investigators concluded that salting immediately after pickling or storing in a cool moist atmosphere prior to salting should decrease the losses from bloating. In a similar type of experiment results indicated that simply piercing the cucumbers with needles practically eliminated balloon type of bloating in cured brine stock (43).

Sneed and Bowers (78) found a significant correlation between each of the three green fruit characteristics: carpel separation, firmness, and skin toughness with balloon bloating in salt stock. Results of this study showed a significant positive correlation between carpel separation and balloon bloating and a negative inverse relationship between either firmness or skin toughness and balloon bloating. Further, results of this study indicated that firmness of green fruit had the highest association with bloating.

Bowers and Bowden (18) also reported that cultivars
with firm salt stock had a low percentage of balloon bloaters, whereas cultivars that produced soft salt stock had a higher percentage of balloon bloaters and a lower percentage of lens bloating. Similarly, Peterson and Ries (74) indicated that cultivars which showed either firm salt stock or firm green stock had a lower percentage of bloaters. Jones et al. (61) also discovered considerable differences among various cultivars in bloater response.

Other investigators have shown that carpel strength, a varietal trait, was related to bloating (5). Results of this research revealed that carpel strength of cucumber slices measured with an Instron Testing Machine was directly related to carpel separation and balloon bloating. In this same report, the authors also demonstrated that post-harvest handling of fruit prior to brining was critical. Test data confirmed that single or repetitive "blows" or dropping of the fruit prior to brining significantly increased the frequency and severity of bloating. Baker et al. (5) also observed that density of the green stock was inversely proportional to balloon bloating. Further, from these data, the authors suggested density sorting using the most dense (sinkers) for brining and the least dense (floaters) for fresh-pack processing as a means of minimizing losses from bloater damage.

Even though numerous factors seem to affect bloater damage, Etchells et al. (34) stated that the primary cause
for bloater damage is an excess gaseous fermentation by numerous genera of yeasts and in some cases Enterobacter (Aerobacter). Owing to the gaseous fermentations the cucumbers can become visually distended with the gas pressure forcing separations in the seed cavity area.

Etchells et al. (34) explained that these gaseous fermentations are encouraged when the initial salt concentration is high, from 12 to 15 percent salt. Under these conditions, the lactic acid microorganisms can not thrive and as a result a large excess of sugar will remain for salt tolerant yeasts with the production of large excesses of gas. Etchells (30) reported that there was definitely a correlation between brine concentration and the beginning and duration of the yeast fermentation.

Another possible consequence of a high initial salinity could be the encouragement of a hydrogen fermentation. Etchells et al. (33) demonstrated that typical fermentations in both 40° and 60° salometer brines were divided into two distinct gas evolution phases. The first phase was brought about by Enterobacter (Aerobacter) where the ratio of hydrogen to carbon dioxide was 1:1. The second phase was brought about by yeasts and consisted primarily of carbon dioxide. Similar observations were reported in another study by Etchells and Jones (32).

Jones et al. (59) discovered a vigorous gaseous fermentation when sugar was added to barrels of partially
cured salt stock. The gas evolution began within a few hours after the sugar was added and practically ceased after 48 hours. In a similar study, Veldhuis et al. (82) clearly demonstrated that adding sugar to brine fails to increase acidity and leads to bloater formation. Further, after slicing the fruit, the data revealed that barrels with added sugar showed three times as many bloaters as the barrels without sugar. Analyses of the brines showed no increase in acidity. These results led the authors to conclude that the increase in bloaters occurred solely as a result of sugar addition which induced an extremely active yeast fermentation.

Increased bloater damage was also discovered when either lactic or acetic acid was added to the fermentation brine (59). The authors explained that the acid tended to inhibit the lactic acid microorganisms allowing an excess of sugar to be available for an active yeast fermentation. These observations were also confirmed by Jones et al. (58).

Jones et al. (59) analyzed gases in the cover brine and inside bloated cucumbers from several different vats. The authors observed that gas obtained from bloaters from any given vat at any given time displayed the same composition as gas obtained at the brine surface. In another study, Etchells and Jones (31) reported that the chief component of gases from the inside of bloated sweet pickles was carbon dioxide.
Etchells et al. (42) discovered that lactic acid microorganisms previously considered as not a serious source of fermentative gases may in fact cause bloating. In this study, pure culture inoculations with \textit{L. brevis}, a heterofermentative microorganism, in one quart jars showed the presence of gas causing an increase in volume of the contents of jars where the lids had been punctured. There was no brine volume increase due to gas accumulation in jars inoculated with \textit{P. cerevisiae} or \textit{L. plantarum} which are known homofermentative lactic microorganisms. Pederson and Albury (71) found that heterofermentations by \textit{L. brevis} resulted in a higher volatile acid content and a higher pH than homofermentative species.

In the study by Etchells et al. (42), the authors reported that the gas pressure produced in jars seeded with \textit{L. brevis} was sufficient to separate the three carpels producing bloaters. Further this type of bloating forced some of the liquid out of the cucumber tissue and into the cover brine contributing to the increase in the volume of the jar contents. From these observations, the authors suggested a mechanism for bloater development. They explained that the fermentative gases were produced only in the brine and diffused into the cucumber in a supersaturated condition by way of the brine. Once inside the cucumber, the gas is released where it accumulates at a structural weakness such as where the three carpels meet resulting in a balloon
bloater or in a gelatinous area around the seeds resulting in a honeycomb defect. Also according to the authors, a lens defect could develop from a honeycomb separation under continued gas stress.

These researchers tested this mechanism for bloater formation by packing number one size, fully cured and de-acidified salt stock pickles in one quart jars and covering with the original cover brine which tested 0.75 percent acid and 12 percent salt (42). To the covering brine the authors added an excess of sodium bicarbonate. The released gas supersaturated the brine, diffused into the cucumber tissue, and instantly produced bloaters typical of those produced in gaseous fermentations of microbial origin.

Fleming et al. (51) discovered that brine fermentation of cucumbers with *L. plantarum* may produce bloated salt stock. This finding surprised the authors in that *L. plantarum* was considered to be a non-gas producer, in that it produces little gas in comparison to heterofermentative lactic acid microorganisms. Also these authors indicated that factors such as NaCl concentration and temperature by influencing the solubility of carbon dioxide may be related to bloater development. Further brine pH may be important as it regulates the proportion of dissolved carbon dioxide of the total carbon dioxide (CO$_2$, H$_2$CO$_3$, HCO$_3^-$, and CO$_3^{2-}$).

Fleming et al. (52) provided still further insight into sources of carbon dioxide which may contribute to
bloating. These investigators measured the relative contributions of the cucumber tissue and the fermenting bacteria in the brine to the total amount of carbon dioxide produced. Results of this study revealed that jars of pasteurized unfermented cucumbers contained 30 mg CO$_2$/100 g cucumbers while pasteurized fermented product contained 114 mg CO$_2$/100 g. According to the authors the carbon dioxide contributed by the cucumbers included that which was present in the fruit at the time of brining plus that formed by respiratory and fermentative activity of the tissue. Further the authors elaborated that the amount of carbon dioxide in cucumbers probably varies greatly and may be influenced by the physiological state of the fruit and storage conditions prior to brining.

Methods Employed to Reduce Bloater Damage

Various techniques to reduce losses from bloater damage have been investigated. Sorbic acid has been utilized as a means of selectively inhibiting the growth of yeast and molds (11, 17, 21, 22, 23, 38). This chemical preservative and its sodium and potassium salts are generally recognized as safe (GRAS) for use in foods under regulations of the U.S. Food and Drug Administration. Chemically speaking, sorbic acid is a conjugated hexadiene which is only slightly soluble in water, however, the salts are highly water soluble.
The exact mode of microbial inhibition of sorbic acid has been studied by certain investigators. York (84) reported that the principle mechanism appeared to be an uncoupling of oxidative phosphorylation. Further results of this study, revealed that sorbic acid may reduce fumarase activity and also react with sulfhydryl enzymes. Freese et al. (53) explained that the uncoupling of oxidative phosphorylation by sorbate and other preservatives probably results from the inhibitions of the cellular uptake of amino acids and other necessary nutrients. Melnick (67) stated that mold inhibition by sorbic acid was due to inhibition of the dehydrogenase system. Deuel (27) conducted extensive toxicological studies revealing that this antimicrobial agent at concentrations up to 5 percent was harmless to dogs. Further Deuel (27) demonstrated that sorbic acid follows the same pathway of oxidation in vivo as the natural 6-carbon fatty acid, caproic acid, found in butterfat.

Borg et al. (17) reported that the usual gaseous fermentation caused by brine yeasts was almost completely inhibited with 0.1 percent sorbic acid with the bloater spoilage being reduced from 60 percent in the control stock to 5 percent in treated lots. However, these authors also reported that the sorbic acid reduced lactic acid bacteria ten fold over the controls. In addition to the reduced level of bacterial counts, the authors found that the
resultant salt stock from sorbic acid treated lots was judged to be inferior in cure and color.

Bell et al. (11) investigated the effect of sorbic acid on the growth of bacteria, yeasts, and mold. Data from this study revealed that the pH of the culture medium was the principal factor controlling the effectiveness of sorbic acid. The authors indicated that all test microorganisms grew in a medium containing 0.1 percent by weight sorbic acid at pH 7.0. Yeasts were inhibited at 0.1 percent by weight of this chemical preservative at pH of 4.5, while the lactic acid bacteria were inhibited at the same concentration at pH 3.5. As the authors explained the reduction in growth of these organisms paralleled the dissociation of sorbic acid over the pH range studied. This demonstrated that the toxic action of sorbic acid was directly related to the concentration of the undissociated acid.

Costilow (22) conducted an experiment involving 123 experimental cucumber fermentations from 0.01 to 0.1 percent by weight sorbic acid. According to this investigator, sorbic acid treatments reduced the occurrence of bloater damage considerably. The occurrence of large pockets was reduced by 75 percent, however, the incidence of small separations was not altered greatly.

According to Costilow (22), the major problems with sorbic acid were a consistent delay in curing and a
bleaching effect. The delay in curing seemed to be dependent upon salt concentration and sorbic acid concentration. The author attempted to explain the bleaching as possibly an oxidation or reduction of chlorophyll to colorless compounds.

As discussed previously, initial brine strength can have an effect on the amount of subsequent gaseous fermentation. With this in mind, Etchells and Hontz (44) have recommended brining pickles on the basis of the average brine-cucumber mass temperature to improve the success of the fermentation. According to this procedure, a 25° salometer brine should be used where the center temperature of the brined mass is 70° to 80° F. If the center temperature measures above 80° F the equilibrated brine strength should be 28° salometer and if the temperature is below 70° F a brine strength of 20° salometer should be employed. In this case 1° salometer is equivalent to 0.26 percent salt by weight.

Fleming et al. (51) discovered a unique method of controlling bloater damage. In this experiment, the authors purged the brine in 1-gallon jars of fermenting cucumbers for 2 hours at a specified time with nitrogen. Purging the brine with nitrogen considerably reduced the expansion volume (rise in volume of brine level due to gas pressure) and the carbon dioxide level. As expected the
removal of carbon dioxide from the brine by sweeping with nitrogen prevented bloater development.

Appreciating the benefits from nitrogen purging, Costilow and Bedford (24) delved deeper into the use of nitrogen to remove carbon dioxide. These researchers examined various methods of purging. These methods included purging in a 6 inch diameter "sidearm" tube connected to the tank and in overhead barrels where the brine was pumped from the tank to the barrels. In one experimental tank, air was substituted for nitrogen. According to the authors, purging in adjacent containers such as barrels or tubes free of cucumbers would be much more efficient than purging from a coil at the bottom of the tank due to the tightness of pack of cucumbers and brine under the headboard. Further, the authors explained that purging in adjacent containers allowed for the continuous circulation of brine due to the purging gas causing an overflow of the brine from the containers. Results from these experiments demonstrated that purging with air encouraged a yeast fermentation and ruined the salt stock. Purging with nitrogen in both the "sidearm" and overhead barrels resulted in a substantial reduction in balloon bloating. According to the authors the largest reduction in balloon bloating occurred when 0.033 percent by weight potassium sorbate was added in a tank circulated by nitrogen purging in a "sidearm" tube.

The authors also reported (24) that pH as it affects
the form of carbon dioxide was critical. They stated that the brine pH must be depressed to near 5.0 soon after brining otherwise bicarbonate accumulates which can not be removed by purging. As was indicated this could be readily accomplished by acidification with vinegar or by adding a relatively small amount of fermenting brine from another container.

In addition to pH, the authors emphasized that the efficiency of nitrogen purging depended upon bubble size and time of exposure (24). The smaller the bubbles, the greater the surface area per unit volume of gas between gas and liquid to allow exchange. Also the higher the column, purge container, the longer the contact period between a given volume of gas and liquid.

Pure culture fermentations have been discussed by several investigators (4, 39, 40, 41, 48, 71, 72). Etchells et al. (40) stated that pure culture fermentation of various vegetables consistently resulted in high quality products free from the usual defects found in natural fermentations. Aurand et al. (4) identified various flavor producing volatile components of pure culture fermentations and compared these to volatile components yielding off flavors from natural fermentations.

Etchells et al. (39) screened various microorganisms for their ability to produce acid in brined cucumbers. According to the authors, the pure culture fermentations
were made possible by first employing gamma radiation (0.83 to 1.00 Mrad) and hot water blanching (151° to 176° F for 5 minutes) to eliminate naturally occurring and competitive microbial groups. A patent was issued to Etchells et al. (41) for a process involving heat shocking cucumbers and packing aseptically into sterile containers followed by inoculation with the desired species. As the authors explained an advantage of this patented process would be that the desirable characteristics of the final product could be manipulated simply by choosing the microorganism.

Recently Etchells et al. (48) suggested a procedure for the controlled fermentation of cucumbers in bulk. The procedure was designed to minimize or eliminate the usual defects such as bloaters, poor texture, poor color, shriveled stock, unclean odor, and off flavor associated with uncontrolled natural fermentation.

The procedure recommended by Etchells et al. (48) included first sanitizing the brine with chlorine. The sanitized brine must then be acidified with vinegar or glacial acetic acid followed by the addition of sodium acetate on the headboards. Next, a special strain of \textit{L. plantarum} which is highly acid tolerant is then inoculated into the brine. According to the authors, under the buffered conditions of this procedure the final pH will hold at about 3.4 to 3.5 allowing the culture to ferment all the sugar within the brine. As explained, without the
buffer additive, the pH could drop to 3.15 inhibiting further growth of the lactic acid microorganisms leaving 0.4 to 0.5 percent residual sugar in the brine. The residual sugar would be then available for a gaseous fermentation by yeasts and possible bloater damage.

**Importance and Methods of Recycling Salt Brine**

Recently the concern for the environment has precipitated research for alternative methods for disposal of salt brines such as reconditioning or recycling (25, 28, 29, 54, 63, 66, 75). Popper *et al.* (75) discussed reconditioning used brine by passing through a column of activated carbon to remove undesirable constituents. Lowe and Durkee (63) and Durkee and Lowe (28) demonstrated a submerged combustion unit which crystallizes salt from used brine. According to these authors, the resultant slurry contained about 6 percent organic matter which could be removed by incineration. The authors explained that since the pH of the reconditioned brine was 10.0, the brine should be neutralized with hydrochloric acid prior to reuse. Further, the dry salt following incineration contained carbon which could be removed by filtration or gravity settling following the preparation of brine for reuse. Durkee *et al.* (29) compared brine prepared from submerged combustion salt with brine prepared from fresh kiln-dried salt. The brine made from reclaimed salt was prepared in 4 different ways: (1)
as received; (2) pH adjusted to match the control; (3)
clarified by settling; (4) pH adjusted and clarified.
Results indicated that there were no differences in the
quality attributes of the salt stock among the treatments.
This suggested to the authors that clarification or neutrali-
zation of submerged combustion salt brines was not
necessary.

Cranfield (25) described a brine recycling system
presently in commercial use. This system involved pumping
the used brine through a regenerative heat exchanger and
heating the brine to 205° F and then cooling to 120° to
130° F. After heat processing, the used brine was then
neutralized to a pH of 4.6 with calcium hydroxide and
allowed to settle. After settling the brine was pumped to
a lixator tank where salt was added and the brine test
increased to saturation. The 100° salometer brine was then
ready for dilution and reuse.

Since possible enzymatic softening in recycled brines
has been a major concern, McFeeters and Palnitker (66)
added fungal pectinase to heated simulated brine. The
authors reported D values of 23.2 seconds at 187° F and
11.6 seconds at 199.4° F.

Geisman and Henne (54) described an efficient method
for recovering salt from the spent brine by adjustment of
brine pH and filtration. According to this procedure, the
pH of the spent brine is adjusted to pH 11.0 with sodium
hydroxide. After base adjustment and 48 hours settling the clear brine is decanted and then neutralized to pH 7.0 with hydrochloric acid. Further, the authors mentioned that the precipitate could be incinerated to recover any salt present and reduce disposal problems.

Aside from the obvious benefits of decreased sewage disposal and reuse of salt, McFeeters and Palnitker (66) discussed other important considerations. These authors reported that the brine resulting from the fermentation of cucumbers in spent brine was higher in pH and titratable acidity due to the presence of buffering compounds. As was indicated earlier, any increase in the buffering ability which allows more of the sugar to be fermented will aid in the success of the fermentation. This may help explain the significant reduction in bloater content which was observed between pickles fermented in recycled spent brine compared to pickles fermented in fresh brine according to the authors.

Vaughn et al. (81) described a method for salt-free storage of olives which would not only eliminate brine disposal problems but also substantially improve texture. As the authors stated, the procedure combines acidity, food preservatives, and anaerobiosis to retard microbial growth. In the study, acetic acid and a 2:1 mixture by weight of acetic and lactic acids with a final concentration of 1 percent were used as preservatives. Reduced aerobic
conditions were maintained with various plastic films and a wax compound sealant. Potassium sorbate and sodium benzoate in concentrations of 0.3 percent by weight were used as preservatives. Results of this research showed that after 6 months storage no spoilage took place and the flavor of all cultivars tested was uniformly as good as or better than the same cultivars processed as salt stock. Also the texture of the olives was improved and shrink which is a problem with some cultivars was virtually eliminated by this procedure. The authors stated that an extension of the method to other types of produce including market cucumbers was tested indicating that the various vegetables retained their firmness and showed no signs of decomposition after 8 months storage.
MATERIALS AND METHODS

Source of Cucumbers

Approximately 2,000 pounds of cucumbers, 1-3/4 to 2-1/8 inches in diameter of mixed cultivars, were obtained from the H. J. Heinz Agricultural Receiving Station in Fremont, Ohio. Following grading the cucumbers were loaded into 15 bushel bin boxes. The cucumbers were transported to the Ohio State University Food Processing Pilot Plant where the fruit were prepared for brine and acidulant preservation.

Sorting and Washing of the Cucumbers

Upon arrival at the pilot plant, the cucumbers were thoroughly washed and sorted to remove the broken, misshappen, and diseased fruit. After washing the fruit, 120 pounds of cucumbers were weighed into each of twelve 32-gallon fermentation containers.

Preparation of Treatment Solutions

Certified reagent grade acidulants were employed including glacial acetic, 88 percent lactic acid, and granular citric acid. Six treatments with two replications were applied as follows: (1) salt brine control; (2) acetic acid 4.4 percent by titration; (3) lactic acid 0.53 percent
by titration; (4) citric acid 0.52 percent by titration; (5) a 2:1 mixture by weight of acetic acid 4.4 percent by titration and lactic acid 0.53 percent by titration; (6) a 2:1 mixture by weight of acetic acid 4.4 percent by titration and citric acid 0.52 percent by titration. To each treatment except for the salt control potassium sorbate was added to give an initial solution concentration of 0.1 percent by weight. A treatment solution weighing 80 pounds giving a 60:40 ratio by weight cucumbers to solution was utilized.

The salt brining control treatment was prepared as described previously. The cucumbers were covered with a 40° salometer brine. After addition of adjustment salt an equilibrated brine strength of 25° salometer was maintained until a 0.6 percent titratable acidity (calculated as lactic) was attained at which time the brine strength was increased 2° salometer weekly to a holding strength of 50° salometer. All treatments were held at 72° F.

Preparation of Acidulant Storage Containers

The volumes for the cucumbers and acidulants were calculated to leave an eight inch headspace in the container as shown in Figure 4. The cucumbers were weighted down with a 6 mil polyethylene plastic sheet fitted over the acidulant surface with the outer rim of the plastic sheet folded up so as to be able to hold water. After sufficient
Figure 4. The Container Construction for Acidulant Storage Treatments
time for shrinking and packing of the cucumbers, distilled water was then added to the top of the sheet to submerge the cucumbers. After 72 hours equilibration, the containers were sealed with a 1/8 inch plexiglass sheet cut to fit the top of the container.

The plexiglass top was sealed to the container with high vacuum desiccator grease. The plexiglass tops were drilled and fitted with two 2 inch (1/4 inch I.D.) rigid polyethylene plastic tubes placed in line through the diameter of the rim of the container two inches inside from the rim. Another two inch (1/8 inch I.D.) rigid polyethylene tube was placed in the center of the plexiglass cover. To the central rigid tube protruding through the plexiglass top, an appropriate length of tygon tubing was attached and extended down the side of the container into the center of the cucumber and acidulant mixture. To each of the three tubes protruding outward from the container appropriate lengths of tygon tubing were attached and pinch clamps were placed at the ends. The outer intersections of the plexiglass top and rigid plastic tubes were sealed with 3M adhesive No. 4693.

The container construction allowed for flushing with compressed gas and for withdrawal of acidulant samples by siphoning. After sealing, the headspaces were flushed with nitrogen from a compressed gas cylinder for 5 minutes.
Flushing was accomplished at frequent intervals throughout the experimental period.

Chemical Analysis

The pH and percent titratable acidity (TA%) were measured with a Beckman pH meter (glass electrode) and by titrating with 0.1N NaOH to a pH of 8.1. The ml NaOH required was converted by calculation to percent acid expressed as acetic or lactic. The sodium chloride content was determined titrimetrically according to AOAC method 32.018 (3).

Accordingly, for each determination, 5 ml of brine was transferred to a 100 ml volumetric flask. Then 45 ml of 80 percent alcohol was added to the flask and the flask was shaken to suspend all the insoluble material. Next 1 ml of concentrated nitric acid and 25 ml of 0.1N silver nitrate were added to the flask and the flask made to 100 ml with 80 percent alcohol. After stirring, the mixture was transferred to 6 centrifuge tubes and centrifuged for 5 minutes. Following centrifugation, 50 ml of the supernatant liquid was pipetted into a 250 ml Erlenmeyer flask with 2 ml of saturated ferric ammonium sulfate and 2 ml of concentrated nitric acid. The solution in the flask was then titrated to a permanent light brown color with ammonium thiocyanate.

The sodium chloride content was then calculated by
dividing the number of ml of silver nitrate used by 2 and subtracting the number of ml of ammonium thiocyanate added. The subtraction difference was multiplied by the factor 0.005843 to obtain the grams salt. Percent sodium chloride was calculated by multiplying the grams salt present by 100/5.

**Bloater Damage Evaluation**

At the end of 2, 4, 6, and 8 months, random samples of 20 cucumbers were withdrawn from each fermentation container and cut longitudinally. The sliced cucumbers were examined and the total number of balloon, lens, and honeycomb bloaters for each sample was recorded.

**Evaluation of Firmness**

At the end of 2, 4, 6, and 8 months, random samples of 10 cucumbers were withdrawn from each fermentation container and the pounds resistance to center puncture was measured with the USDA Fruit Pressure Tester with a 5/16 inch tip. An initial sample of 25 pounds was withdrawn and pressure tested as an indication of fresh fruit firmness. Further as declared by Etchells (46) the adjective descriptions corresponding to pressure test values are as follows:

<table>
<thead>
<tr>
<th>Pressure Test (pounds)</th>
<th>Adjective Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 and above</td>
<td>Very Firm</td>
</tr>
<tr>
<td>16 to 19</td>
<td>Firm</td>
</tr>
</tbody>
</table>
Pressure Test (pounds)  Adjective Rating
11 to 15  Inferior
5 to 10  Soft
4 and less  Mushy

Evaluation of Color

To obtain an objective evaluation of pickle color the Agtron M-30A instrument was employed. The M-30A with the wide area viewer provides accurate and repeatable measurements of many non-homogenous parti-colored products such as potato chips. The reflected light from the sample is largely unaffected by particle size, particle geometry, irregularities, voids, and shadows (1).

Accordingly, at the end of 2, 4, 6, and 8 months, representative samples were withdrawn for color determination. Some representative samples were peeled and some representative cucumbers were sliced crosswise to evaluate both skin and internal color. The peels or slices were filled into the wide angle cup so that no spaces in the bottom of the cup were left exposed. The spectral reflectance was measured in the red, blue, and green bands for both slices and peels. The instrument was standardized to 0 percent reflectance with the standard black disc and to 90 percent reflectance with the standard white disc.
Preparation for Flavor Evaluation

At the 8-month analysis period, 8 pound samples of the acidulant and salt stock were removed (4 pounds from each of the duplicate treatments). The salt stock was freshened whole without slicing at 72° F by soaking in an equal weight of tap water changing the water every 8 hours for a 24-hour period. The acidulant stock was sliced into 1/8 inch slices with a vegetable slicer and freshened in a similar manner as the salt stock. Air was introduced into the freshening water continuously to agitate the medium and hasten desalting and deacidification.

After freshening, the whole cucumbers were sliced as previously described and all treatments were rinsed with tap water. The cucumber slices from all treatments were prepared as processed dills by filling 270 g of sliced material into 16 oz jars. The salt brine control pickles were covered with a standard process dill brine containing 1262 ml vinegar (5 percent acid distilled), 2523 ml tap water, 105 g table salt, 67 g sugar, and 4 g dill emulsion (Seasoning Mills No. 20471). The acidulant stored cucumber pickles were packed in the salt brine mentioned above, and in a no salt medium which contained the same ingredients except no salt was added and the sugar increased to 100 g.

The final two cover media were prepared from the acetic acid tank storage solutions. One acidulant solution with salt contained 945 ml of the storage acetic acid, 945
ml tap water, 54 g salt, 33 g sugar, 2 g dill emulsion. The other cover medium was the same as the previously described storage acetic solution except no salt was added and the sugar increased to 51 g.

All jars were hot filled at 170° F. Immediately after filling, all jars were capped with "twist off" caps and pasteurized in a hot water bath to 165° F internal temperature for 15 minutes. After a 2 week equilibration period, the processed cucumber pickles were opened and presented to a taste panel consisting of 10 judges. The judges were instructed to rate the color, texture, and flavor of the samples on a rating scale of 1 to 10, 1 being off and 10 being perfect.

Statistical Analysis

The data of this study were analyzed with the aid of the Wang Programmable Calculator of the Agricultural Research Department, Heinz USA, division of H. J. Heinz Company, Bowling Green, Ohio. The split-plot analysis of variance design for factorial experiments as described by Steel and Torrie (79) was employed. This procedure allowed the singular effects of the factors, acidulant storage and time, to be shown as well as any interaction between these two factors. Mean separation was accomplished with the use of Duncan's New Multiple Range Test (79).
PRESENTATION OF RESULTS

Storing cucumbers in acidulant solutions did not significantly reduce the quality and usability of the cucumber pickles in comparison to the salt brine control. Data obtained in this study revealed that the type of acidulant and the length of storage may affect both bloater damage and firmness or cucumber texture. No significant interactions of time with type of preservation, salt or acidulant, occurred. All data presented in either graphic or tabular form except for the flavor panel data represent the average of duplicate treatments. In the following tables and figures, the abbreviations A & L and A & C represent the acetic and lactic and the acetic and citric acidulant combination treatments respectively. The acidulant storage treatments with lactic and citric acids by themselves spoiled within 4 months and were subsequently discarded. Data revealing the firmness values for the lactic and citric treatments during 2 and 4 months of storage are presented in Figure 5.

Comparison of Treatment pH Values and Titratable Acidities

The curves in Figures 6 and 7 show the initial, equilibrated, and monthly pH values and titratable acidities
Figure 5. Fruit Pressure Test Scores for Lactic and Citric Preserved Cucumber Pickles after 2 and 4 Months Storage
Figure 6. Relationship Between Length of Storage and pH for Brine and Acidulant Preserved Cucumbers
Figure 7. Relationship Between Length of Storage and Percent Acid for Brine and Acidulant Treatments
for the various treatments. It can be seen from these figures that the initial pH increased from 2.7 and equilibrated from 3.3 to 3.5 for all acidulant treatments. In general, the titratable acidity decreased from 1.8 to 2.5 percent acid after equilibration for the various acidulant preserved cucumber pickles. After 8 months storage the pH increased slightly and the titratable acidity decreased slightly.

In the case of the salt brine control, the cucumbers were covered initially with a 40° salometer brine, pH 8.8, which equilibrated to 25° salometer after the addition of adjustment salt. After fermentation, the pH of the salt control varied between 3.2 and 3.4 during the 8 months of storage. A 0.6 percent lactic acid was attained in approximately 3 weeks and the 50° salometer holding strength after 17 weeks.

Changes in Color for Acidulant and Salt Treatments

The changes in skin color for the peeled cucumber samples are depicted by the curves in Figures 8, 9, and 10. Data in these graphs reveal considerable changes in spectral reflectance for all treatments within the 2-month storage period in the green mode, Figure 9, and small changes during the 8 months of storage in the red and blue modes. The Agtron readings of internal slice color are shown in Figures 11, 12, and 13. In this case decreases in
Figure 3. Relationship Between Length of Acidulant and Brine Storage and Skin Color Changes as Measured by Agtron Spectral Reflectance in the Red Mode
Figure 9. Relationship Between Length of Acidulant and Brine Storage and Skin Color Changes as Measured by Agtron Spectral Reflectance in the Green Mode
Figure 10. Relationship Between Length of Acidulant and Brine Storage and Skin Color Changes as Measured by Agtron Spectral Reflectance in the Blue Mode
Figure 11. Relationship Between Length of Acidulant and Brine Storage and Interior Slice Color Changes as Measured by Agtron Spectral Reflectance in the Red Mode
Figure 12. Relationship Between Length of Acidulant and Brine Storage and Interior Slice Color Changes as Measured by Agtron Spectral Reflectance in the Green Mode.
Figure 13. Relationship Between Length of Acidulant and Brine Storage and Internal Slice Color Changes as Measured by Agtron Spectral Reflectance in the Blue Mode
spectral reflectance occurred in all three modes. Generally speaking, there are small differences between the salt brine control and the acidulant storage treatments for external and internal spectral reflectance.

Evaluation of Firmness

The results for the pressure test scores for the salt and acidulant stock cucumber pickles at the 2-, 4-, 6-, and 8-month analysis periods are presented in Figure 14. As can be seen from the data, the acetic acid storage solution resulted in the only cucumber pickles in the firm category with a 17.7 pound average, 3 pounds above the salt control after 8 months storage. The results reveal an apparent decrease in firmness from the 2-month analysis period for all treatments except the acetic and lactic combination. From Table 1, where data were combined for all treatments and the effects of time analyzed, results show that for firmness the means for the 2-, 6-, and 8-month periods were statistically equal and the 2- and 4-month means were equal. The analysis of variance test shown in Table 1 also reveals that the firmness of cucumbers stored in acetic acid was greater than the salt control which was equal statistically to the acetic and lactic combination treatment. Finally the data in Table 1 proves that there was no significant interaction between storage time and treatment method of preservation (T x T).
Figure 14. Effect of Acidulant and Brine Preservation on Cucumber Pickle Firmness as Measured with the USDA Fruit Pressure Tester.
TABLE 1

FIRMNESS SCORE DATA ANALYSIS OF VARIANCE FOR ACIDULANT AND BRINE PRESERVED CUCUMBER PICKLES

<table>
<thead>
<tr>
<th>Factor</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F*</th>
<th>Treatment</th>
<th>Pounds Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>17.37</td>
<td>5.71</td>
<td>14.49*</td>
<td>2 mos.</td>
<td>16.25 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 mos.</td>
<td>14.53 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 mos.</td>
<td>15.38 ab</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8 mos.</td>
<td>16.34 b</td>
</tr>
<tr>
<td>Treat</td>
<td>3</td>
<td>32.43</td>
<td>10.81</td>
<td>13.51*</td>
<td>Brine</td>
<td>14.93 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A &amp; L</td>
<td>14.49 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A &amp; C</td>
<td>15.99 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acetic</td>
<td>17.09 c</td>
</tr>
<tr>
<td>T x T</td>
<td>9</td>
<td>7.40</td>
<td>0.82</td>
<td>1.03 NS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a* = significant, NS = not significant at .05 level.

bMeans followed by same letter are not significantly different at .05 level.
Evaluation of Bloater Damage

The data displayed in Figure 15 relate the effect of storage time and acidulant and brine preservation methods on total bloaters including balloon, lens, and honeycomb. From the figure, it is apparent that most of the bloater damage occurred during the first 2 months for all treatments. Also data seem to indicate that there may be a gradual increase in bloater damage with time for the acidulant treatments. This is confirmed by the analysis of variance test shown in Table 2. In this case, after combining the data for all treatments and analyzing the time factor significant differences due to time did occur. The statistical test also reveals that the amount of bloater damage produced in the salt preservation treatment was statistically equal to the acetic and lactic and the acetic and citric combination treatments. Further, significantly less bloater damage occurred with the acetic acid storage treatment. No time and temperature interaction (T x T) affected bloater damage in this study.

Organoleptic Acceptability of Dill Slices

Data from the sensory panel evaluation and the subsequent statistical analysis of the salt and acidulant stock prepared as process dill slices are presented in Tables 3 and 4. These data show that there were statistical differences among judges for flavor or individual preferences for
Figure 15. Effect of Acidulant and Brine Preservation on Total Percent Bloaters Including Balloon, Lens, and Honeycomb Defects
# TABLE 2

**BLOATER DAMAGE DATA ANALYSIS OF VARIANCE FOR ACIDULANT AND BRINE PRESERVED CUCUMBER PICKLES**

<table>
<thead>
<tr>
<th>Factor</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>( F^a )</th>
<th>Treatment</th>
<th>Bloaters (%)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>1946.09</td>
<td>648.70</td>
<td>21.66 *</td>
<td>2 mos.</td>
<td>45.63 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 mos.</td>
<td>66.88 c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 mos.</td>
<td>56.88 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8 mos.</td>
<td>61.25 bc</td>
</tr>
<tr>
<td>Treat</td>
<td>3</td>
<td>12758.59</td>
<td>4252.86</td>
<td>86.41 *</td>
<td>Brine</td>
<td>70.63 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A &amp; L</td>
<td>69.38 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A &amp; C</td>
<td>67.50 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acetic</td>
<td>23.13 a</td>
</tr>
<tr>
<td>T x T</td>
<td>9</td>
<td>782.03</td>
<td>86.89</td>
<td>1.77 NS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) = significant, NS = not significant at .05 level.

\(^b\)Means followed by same letter are not significantly different at .05 level.
TABLE 3

THE ORGANOLEPTIC EVALUATION OF SALT AND ACIDULANT
STOCK PREPARED AS DILL SLICES

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Color</th>
<th>Texture</th>
<th>Flavor</th>
<th>Panel Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brine</td>
<td>6.7 bcd</td>
<td>7.2 c</td>
<td>7.3 cd</td>
<td>good</td>
</tr>
<tr>
<td>A &amp; L</td>
<td>7.2 cd</td>
<td>5.9 ab</td>
<td>7.8 d</td>
<td>good</td>
</tr>
<tr>
<td>A &amp; C</td>
<td>5.9 ab</td>
<td>5.3 a</td>
<td>5.7 b</td>
<td>fair</td>
</tr>
<tr>
<td>Acetic</td>
<td>6.3 abc</td>
<td>5.7 ab</td>
<td>6.6 bc</td>
<td>fair</td>
</tr>
<tr>
<td>Acetic</td>
<td>7.6 d</td>
<td>6.9 bc</td>
<td>7.3 cd</td>
<td>good</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No Sodium Chloride</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A &amp; L</td>
<td>5.7 a</td>
<td>5.7 ab</td>
<td>3.8 a</td>
<td>flat, poor</td>
</tr>
<tr>
<td>A &amp; C</td>
<td>6.8 bcd</td>
<td>6.9 bc</td>
<td>4.4 a</td>
<td>bland</td>
</tr>
<tr>
<td>Acetic</td>
<td>6.5 abc</td>
<td>6.9 bc</td>
<td>4.6 a</td>
<td>bland</td>
</tr>
<tr>
<td>Acetic</td>
<td>7.5 d</td>
<td>6.4 abc</td>
<td>4.2 a</td>
<td>bland</td>
</tr>
</tbody>
</table>

aBased on panel of 10 judges with a scale: 10=perfect; 7, 8, and 9=good; 4, 5, 6=fair; 2 and 3=poor and 1=off. Means followed by same letter are not different at .05 level.

bRefers to whether or not salt was used in packing.

cRefers to the use of the acetic storage solution in packing.
TABLE 4
ANALYSIS OF VARIANCE OF THE ORGANOLEPTIC EVALUATION OF COLOR, TEXTURE AND FLAVOR FOR ACIDULANT AND BRINE PRESERVED CUCUMBER PICKLES PREPARED AS DILL SLICES

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>Fa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Judges</td>
<td>9</td>
<td>10.62</td>
<td>1.18</td>
<td>1.19 NS</td>
</tr>
<tr>
<td>Treatments</td>
<td>8</td>
<td>35.49</td>
<td>4.44</td>
<td>4.49 *</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>71.18</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Judges</td>
<td>9</td>
<td>62.10</td>
<td>6.90</td>
<td>4.88 *</td>
</tr>
<tr>
<td>Treatments</td>
<td>8</td>
<td>37.76</td>
<td>4.72</td>
<td>3.34 *</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>101.80</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td><strong>Flavor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Judges</td>
<td>9</td>
<td>73.79</td>
<td>8.20</td>
<td>5.54 *</td>
</tr>
<tr>
<td>Treatments</td>
<td>8</td>
<td>190.82</td>
<td>23.85</td>
<td>16.12 *</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>106.51</td>
<td>1.48</td>
<td></td>
</tr>
</tbody>
</table>

aNS = not significant, * = significant at .05 level.
the treatment samples. Also there were statistical differences due to treatments. For flavor of the acidulant treatments packed with sodium chloride, the judges rated the acetic and lactic treatment slightly higher (7.8) but not significantly different from the salt control (7.3) or the acetic tank solution (7.3). The panel members remarked that these three treatments were good. The acetic acid tank storage treatment (7.3) and the salt control (7.3) were rated slightly higher but not statistically different from the acetic slices prepared with fresh vinegar (6.6).

Where no sodium chloride was used in the preparation of the cover media, the flavor scores were reduced to the poor and fair categories. The judges indicated that these samples were flat, bland, and poor. Further, as can be seen from Table 3, lower ratings for the acidulant treatments prepared without sodium chloride were statistically equal to each other and significantly inferior to samples packed with salt.

For color and texture, differences due to treatment were not as readily apparent as for flavor. From Tables 3 and 4, one can see that in the case of texture the judges differed significantly in their ratings of texture. For color, no significant differences were obtained among judges for color preference. For both of these quality attributes, the judges rated the brine control statistically equal to the acetic storage samples regardless of salt
additions in the preparation of the acidulant storage slices. For all the sample dill slices regardless of preservation method and salt addition, the panel members rated the color and texture fair to good.

**Chemical Analysis of Dill Brines**

Table 5 reveals the results of the chemical analysis of the equilibrated brines for the cucumber pickles prepared as dill slices and presented to the flavor panel. These data show no apparent differences in the equilibrated pH values and titratable acidities among the various treatments. The brine preserved slices did equilibrate higher in percent salt than the acidulant treatments.
### TABLE 5
CHEMICAL ANALYSIS OF THE EQUILIBRATED COVER BRINES FOR CUCUMBER PICKLES PREPARED AS DILL SLICES

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent Salt</th>
<th>pH</th>
<th>Percent(^a) TA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sodium chloride(^b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brine Control</td>
<td>1.44</td>
<td>3.4</td>
<td>0.77</td>
</tr>
<tr>
<td>A &amp; L</td>
<td>0.63</td>
<td>3.4</td>
<td>0.82</td>
</tr>
<tr>
<td>A &amp; C</td>
<td>0.65</td>
<td>3.3</td>
<td>0.87</td>
</tr>
<tr>
<td>Acetic</td>
<td>0.64</td>
<td>3.4</td>
<td>0.80</td>
</tr>
<tr>
<td>Acetic(^c)</td>
<td>0.81</td>
<td>3.3</td>
<td>0.78</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>No sodium chloride(^b)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A &amp; L</td>
<td>0.0</td>
<td>3.3</td>
<td>0.80</td>
</tr>
<tr>
<td>A &amp; C</td>
<td>0.0</td>
<td>3.3</td>
<td>0.83</td>
</tr>
<tr>
<td>Acetic</td>
<td>0.0</td>
<td>3.4</td>
<td>0.80</td>
</tr>
<tr>
<td>Acetic(^c)</td>
<td>0.0</td>
<td>3.3</td>
<td>0.82</td>
</tr>
</tbody>
</table>

\(^a\)Refers to percent titratable acidity (TA) expressed as acetic.

\(^b\)Refers to whether or not sodium chloride was used in the packing cover medium.

\(^c\)Refers to the use of the acetic acid tank storage solution in the packing cover medium.
DISCUSSION OF RESULTS

The salt brining process as used commercially allows cucumbers not only to be cured but also to be stored for significant periods after the holding brine strength is attained. The function of the salt in the process is to enable the desirable salt tolerant lactic acid microorganisms to ferment the sugars and thus cure the cucumbers while inhibiting the growth of undesirable spoilage microorganisms. Nevertheless, research has shown that even the most desirable homofermentative lactic acid species can produce sufficient gas to damage cucumbers in brine fermentation. Because of this some researchers have taken the approach of mechanically controlling the amount of fermentative gases by continually removing the gas with methods such as nitrogen purging. Further, researchers have expressed the belief that with pure culture salt pollution problems could be reduced since less total salt would be required for storage under these conditions (48). This is so because with a buffered brine all of the biologically usable sugar would be converted and not available for future microbial growth, thus lowering the salt requirement to prevent spoilage.

Vaughn et al. (81) revealed that olives and other
produce including market cucumbers could be stored in salt free acidulant solutions with chemical preservatives under anaerobic conditions thus eliminating the need for salt and the subsequent disposal of the salt in the spent brine. It seemed reasonable as the intent of this study will show that under conditions similar to those described by Vaughn et al. (81) that bloater damage and cucumber softening could be reduced by inhibiting the primary microbial sources of this spoilage. Further, with this approach the advantages of the salt brine process allowing cucumbers to be held for significant time periods would still be retained.

Evaluation of Color

Preliminary experiments were initiated to find a suitable method for objectively determining the differences in color between brine and acidulant preserved cucumbers. The Agtron M-30A with the wide angle viewer was selected because it has been designed to measure the relative spectral reflectance characteristics of non-homogenous and parti-colored products. As indicated earlier, the reflected light from the sample represents an average color character of the sample which is largely unaffected by particle size, particle geometry, irregularities, voids, and shadows. This instrument seemed to meet the prerequisites for analyzing external color of cucumbers since large variations
in the raw fruit skin color occur due primarily to physiological maturity of the individual fruit.

After examining changes in spectral reflectance of skin color in the red, green, and blue modes shown in Figures 8, 9, and 10 respectively, there does not appear to be any difference in the external skin reflectance patterns for these three modes. It is apparent from Figure 9 that considerable decreases in reflectance occurred within the first 2 months of storage in the green mode for all treatments. This change in spectral reflectance is probably due to the acid conversion of chlorophyll to more yellowish pheophytin (68, 70).

For internal slice color, Figures 11, 12, and 13 again there does not appear to be considerable differences among the treatments, however the salt control equilibrated at a slightly lower reflectance than the acidulant treatments for all three modes. This seems logical since initially the internal color of the fresh cucumber is snow white and then as the occluded air is expelled the interior is converted to a translucent light green.

In relating the objective determination to visual observations of the internal color of acidulant stored fruit, some agreement may exist. The acidulant stored fruit appeared to be slightly mottled in that some white areas remained as depicted in Figure 16. Perhaps the slightly higher reflectance readings can be attributed to
Figure 16. Appearance of Brine and Acetic Acid Preserved Cucumber Slices
the mottled white areas with the acidulant stored fruit and thus more reflectance of all colors in relation to the brine control. If this mottled appearance is due to the retention of air in the tissue, then this should not be a major problem since simply agitating the cucumbers in the desalting or processing water prior to in-jar packing will hasten and facilitate the expulsion of occluded air and thereby yield a uniform slice color. Another possible explanation for this slightly bleached appearance may be the potassium sorbate. As reported previously, potassium sorbate can cause a bleaching effect on cucumbers in brine fermentation (17, 22). After preparing the acidulant stored cucumbers as dill slices, the final color was lighter, more yellow, than the salt brine control slices similar to the color of fresh-pack slices. Regardless of the cause of the lighter color with acidulant preservation, the flavor panel members rated the slices as acceptable.

Perhaps, the most significant application of these results show that objective color evaluation or quality control with the Agtron may be feasible. Since considerable changes in the green mode were obtained for both slices and skin peels, further work expanding the spectral reflectance scale in the green mode in conjunction with sensory panel ratings could possibly define acceptable limits. This could standardize this important quality
attribute of pickles which has traditionally been poorly defined.

**Evaluation of Firmness**

The statistical analysis, Table 1, of the combined firmness data for the time factor reveals that the firmness mean for the 4-month analysis period was equal to the 6-month analysis period and the 6-month analysis period was statistically equivalent to all other storage periods. The reason for the lower readings during the 4-month period in relation to the 2- and 8-month analysis periods is not known. Breene *et al.* (20) reported variations as high as 12 percent with the USDA Fruit Pressure Tester between different investigators. In this study, the same investigator was employed but the analysis periods were two months apart. Thus regardless of statistical significance the lower readings may be due to factors other than time. No time and temperature interaction was obtained which implies that under the conditions of this experiment acidulant storage was as good as salt storage in retaining firmness for 8 months storage.

The effects on firmness due to method of preservation or treatment indicate that the brine control and acetic and lactic combination treatments were statistically equal to each other and slightly lower than the acetic and citric combination which was lower than the acetic acid storage
solution. As mentioned previously, acidulant treatments with lactic or citric acids alone spoiled within 4 months. Data in Figure 5 reveal that the cucumbers from these treatments were extremely soft. Further there was a distinct off-odor from the cucumbers stored under these conditions.

It should be noted that it was difficult in some cases to collect the firmness readings. The amount of bloating in the salt and acidulant combination treatments was relatively high and thus even though sincere efforts were made to avoid pressure testing hollow center pickles, some bloated pickles were probably evaluated which could explain the relatively low scores for the salt control and the acidulant combination treatments.

The important aspect of this part of the study lies in the fact that no significant deterioration in cucumber firmness occurred during 8 months of storage. The results seem to indicate that acetic acid alone was superior to the combination acid treatments for firmness. This observation is consistent with previous studies showing that acetic acid is the best acidulant precluding the use of lactic, citric, malic, or oxalic in the manufacture of fresh-pack pickles (15). Further, these results agree with Vaughn et al. (81) in that these researchers found no visible signs of decomposition of vegetables including market cucumbers for 8 months storage.
Even though the results of this study indicate no softening upon storage, the potential for cellulolytic enzyme activity still remains. As mentioned earlier, research has indicated that cucumber softening due to enzyme activity can be a problem in low salt brines (12). Therefore, further research into the potential for softening due to inherent plant enzymes during acidulant storage is necessary. This research should address the question of the need to thermally inactivate enzymes prior to acidulant storage.

Evaluation of Bloater Damage

The data shown in Figure 15 and Table 2 reveal that time was a significant factor affecting bloater damage when data for all treatments were combined. Nevertheless, most of the damage occurred for all treatments during the first two months of storage. Further, as indicated in Table 2, the treatment or method of preservation significantly influenced the amount of bloater damage with the acetic acid storage solution resulting in considerably less bloater spoilage than the salt control or the acidulant combination treatments.

When analyzing the data presented in Figure 15 and Table 2, it should be taken into consideration that the data indicate total bloaters from all three types of bloating regardless of severity. Generally the bloater
damage was moderate in all cases. This is important because the degree of severity of the defect will dictate how much of the fruit can be utilized.

As indicated before, an attempt was made to reduce the primary sources of carbon dioxide and thus bloating by storing cucumbers in relatively high acid solutions with potassium sorbate under nitrogen in a sealed container. Despite these precautions, a significant amount of bloater damage still occurred with the combination acidulant mixtures and to a lesser extent with the acetic acid storage solution. The reasons for the extent of bloater damage are not known, however, similar observations have been reported in other studies. Monroe et al. (69) discovered a considerable amount of bloater damage in unfermented pasteurized pickles. Along with the bloater damage, these investigators reported a "split skin" defect whereby the skin peeled away from the cucumber flesh. Fleming et al. (52) demonstrated that the respiratory or fermentative activity of the cucumber tissue can be a source of carbon dioxide contributing to bloater damage. Further, these authors stated that the degree of respiratory activity of the cucumber tissue probably varies with the physiological state of the fruit, storage conditions prior to brining, and the inhibitory effect of salt and acid diffusing into the tissue during brining.

The importance of pH as it affects the form of the
carbon dioxide has been of concern to some investigators (24, 51). Possibly the diffusion of acid into the fruit could liberate the carbon dioxide from bicarbonate or carbonate increasing the internal stress of the acidulant stored cucumbers. Finally a possible explanation for the bloater damage in the acidulant storage treatments could be that some microbial growth with the production of carbon dioxide occurred. Nevertheless, any contributions of gas and thus bloater damage from microbial origin was minimal in this study since the acidulant solutions remained clear and free from active fermentation.

The substantial reduction in bloater damage as shown in this part of the study and as depicted in Figure 16 has a considerable potential. As can be seen from the data in Figure 15, the acetic acid storage solution yielded 50 percent less bloater damage than the brine control after 8 months storage. The potential is readily appreciated when one considers that it has been conservatively estimated that the pickle industry loses well over one million dollars annually due to bloater damage (34).

**Organoleptic Acceptability of Dill Slices**

Results of the flavor panel evaluation of the process dill slices prepared from the brine and acidulant preserved cucumbers indicate that in most cases acidulant stored treatment slices were as good or better than the salt
control slices for flavor, color, and texture. Further, these data show that sodium chloride (salt) is a necessary component for the flavor of process dill slices. When it is eliminated during storage it must be added back in the jar. These data are consistent with earlier observations that when fresh-pack dill products were packed with low amounts of sodium chloride the flavor scores were poor and unacceptable (16). Nevertheless, Bell et al. (16) reported that since the raw cucumber is relatively low in sodium, one could prepare low sodium pickle products within the tolerance limits for sodium restricted diets by using salt substitutes. However, these authors admitted that it would be necessary to desalt salt stock cucumbers considerably before the processed salt stock cucumbers could be used for these diets. It follows that acidulant storage in salt free solutions could increase the versatility of the packer by allowing him to add salt for regular products or add salt substitutes for dietetic products without significantly increasing the processing or desalting requirements.

Since the acidulant storage solutions were free from active fermentation, the acidulant solutions were clear relative to the brine control. Therefore, it was decided to prepare a cover medium utilizing the acetic acid storage solution rather than fresh acetic acid (vinegar). The data in Table 3 indicate that the average numerical rating for flavor with the storage acid solution was 7.3 equivalent to
the brine control. This implies that storing in salt free solutions may not only reduce the problems of disposal of spent brines but also the need to dispose of the biodegradable storage acid solution since it could be used in the packing of the cucumber pickles.

In this experiment, the acidulant preserved cucumbers were freshened or deacidified similarly to the salt stock control in order to explore the possibilities for reuse of the acidulant solution. Since the equilibrated percent acetic acid would be just under 2, commercially it may be feasible simply to pack the fruit with water thus reducing the acid to a palatable level. Possibly the tank storage acidulant solution could then be used in other storage tanks or reconditioned and used during the fresh-packing season. The possibility of reuse for these purposes ultimately would be dictated by whether or not there would be any buildup of undesirable constituents in the solution.

It is necessary to be able to reuse the storage acid solution for acidulant storage to be a good alternative for brine preservation. This is true because, presently, research has developed methods to recover or recycle salt. Thus, in the future salt pollution may not be as great a problem as it is now. Also it seems rather inefficient and expensive to annually acquire vinegar to store the cucumbers and then dispose of the acid as is presently done with salt by most of the brining industry. Further, reuse would
avoid disposing of the vinegar which otherwise would add considerably to the BOD of the waste water.

Need for Further Research

In general, the results of this study show that acidulant preservation of cucumbers in bulk for storage may be an acceptable alternative to brine preservation. Therefore, further research seems justifiable. Research should thoroughly investigate and identify any microorganisms capable of growth under acidulant storage conditions. This is necessary since without a fermentation one would expect the reducing sugar level to remain relatively high in acidulant storage solutions. Thus possibly there would be a potential for growth by acid tolerant microorganisms under prolonged storage. As mentioned earlier, research should determine the potential of softening due to cellulolytic plant enzymes and whether or not precautions should be taken to insure no decrease in quality.

It would be most interesting to learn more concerning bloater damage in unfermented cucumber pickles stored under acidulant preservation methods. Possibly one could gain more insight into this area by closely monitoring carbon dioxide levels within the cucumbers and acidulants. The possibility of some carbon dioxide contribution from microbial sources could be determined by microbiological plating means or by monitoring reducing sugar levels. If it can be
determined that cellular respiration in cucumber tissue is the primary source of bloater damage, then possibly this spoilage could be reduced by blanching the fresh fruit to decrease respiration prior to filling the acidulant storage tanks.

Ultimately, since salt free storage of cucumbers in acidulants is similar to fresh-packing of raw cucumbers, it seems reasonable to conclude that cucumbers could be stored in the packing media including vinegar and appropriate spices under aseptic conditions (as is done with fresh-packing of raw cucumbers). Aseptic storage in a closed vessel similar to this study would be of considerable benefit in being more sanitary than the present salt brining procedure and also decreasing the chance of incidental contamination which can occur in open storage tanks. This could reduce the need for salt brining cucumbers and for disposal of spent brines since the cucumber solids and storage mediums would be aseptical. Filled into the jars. Obviously aseptic filling would depend upon the engineering mechanisms of pumping cucumber solids and the total cost of the system.
SUMMARY AND CONCLUSIONS

Raw cucumbers were stored for 8 months in salt free acidulant solutions with initial concentrations of 4.4 percent by titration for acetic acid, a 2:1 mixture by weight of acetic acid 4.4 percent by titration and lactic acid 0.53 percent by titration, a 2:1 mixture by weight of acetic 4.4 percent by titration and citric 0.52 percent by titration. Two other acidulant treatments utilized lactic and citric acids alone in concentrations of 0.53 and 0.52 percent by titration respectively. To each acidulant treatment, potassium sorbate was added to give an initial solution concentration of 0.1 percent by weight. The cucumbers and acidulants were held in a sealed container under nitrogen. Cucumber samples were withdrawn after 2, 4, 6, and 8 months storage to determine the degree of bloater damage, firmness, and external and internal color. Further, samples were withdrawn after 8 months storage and packed as process dill slices to determine the organoleptic acceptability. All comparisons in this study were made in relation to a standard salt brine control treatment.

The acidulant treatments with lactic and citric acids alone spoiled within 4 months. Factors significantly affecting bloater damage and cucumber firmness were storage
time and treatment method of preservation. Storage in acetic acid resulted in significantly less bloater damage and higher firmness scores than the salt brine control treatment. The final color of slices from acidulant storage treatments was lighter than the salt control but still acceptable. In addition no significant interactions of time or treatment method of preservation occurred in the analysis for either bloater damage or cucumber firmness.

The following conclusions can be drawn from this study:

1. Cucumbers can be stored in acetic acid solutions for up to 8 months without noticeable decreases in quality and thus may be a feasible alternative to brine preservation.

2. Cucumbers can not be successfully preserved in lactic or citric acids alone in initial concentrations up to 0.53 and 0.52 percent respectively.

3. Storing cucumbers in acetic acid can decrease bloater damage and thereby reduce economic losses from this type of spoilage compared to salt brining.

4. Acidulant storage in acetic acid does not adversely affect cucumber firmness up to 8 months storage.
5. The internal color of the acidulant stored fruit is somewhat bleached and mottled with white areas possibly due to occluded air in the tissue.

6. The color of process dill slices prepared from acidulant stored fruit is lighter than slices prepared from salt stock, more like fresh-pack slices.

7. The color, texture, and flavor of process dill slices prepared from acidulant stored cucumbers are organoleptically acceptable and the storage acid solution may be reused in the packing of the finished pickle products if desired.
LITERATURE CITED


